Flour Pasting Properties of Wild-Type and Partial Waxy Soft Wheats in Relation to Growing Environment-Induced Fluctuations in Starch Characteristics

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ABSTRACT

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To relate growing environment-induced differences in wheat (*Triticum aestivum* L.) flour pasting properties with fluctuations in starch characteristics, starch characteristics of flours milled from wild-type and partial waxy wheat genotypes grown at two diverse locations (irrigated vs. rain-fed) over two successive crop years (2000, 2001) were analyzed. The crop year or growing location that possessed the highest peak and breakdown viscosity values exhibited the highest mean flour total starch (FTS) content, while that exhibiting the highest trough, final, and setback viscosities possessed the highest mean A-type granule content. Correlation analysis across growing environments provided additional evidence for associations between flour pasting properties and flour/starch characteristics. Fluctuations in mean FTS content were associated with flour peak (r = 0.95) and breakdown (r = 0.93) viscosity differences, while variability in A-type granule content was strongly correlated with fluctuations in trough (r = 0.82), final (r = 0.96), and setback (r = 0.99) viscosities. Peak viscosity was also negatively correlated with total (r = –0.78) and lipid-complexed (r = –0.72) amylose contents. Of the flour/starch characteristics measured, variability in FTS and A/B-type granule contents best explained growing environment-induced fluctuations in flour pasting properties.

Growing environment has been shown to significantly impact the swelling and pasting properties of flour obtained from wheat (*Triticum aestivum* L.) cultivated under diverse environmental conditions (Dengate and Meredith 1984; Crosbie et al 1992; Konik et al 1993; Lin and Czuchajowska 1997; Morris et al 1997). Starch, the major constituent of wheat, is the primary contributor to wheat flour pasting behavior and is ultimately responsible for variability in flour pasting properties. A considerable research effort has been devoted to understanding the influence of specific environmental factors on wheat starch characteristics and properties, which has been summarized in detailed reviews (Tester and Karkalas 2001; Dupont and Altenbach 2003). Temperature during growth, particularly during grain filling, is perhaps one of the most studied and significant environmental parameters influencing starch characteristics. An excessively high temperature during growth reduces starch accumulation in wheat kernels (Wiegand 1981; Bhullar and Jenner 1986,1991a,b; Shi et al 1994; Hurkman et al 2003) due to reduced starch synthase activity (Keeling et al 1993) and a curtailed grain filling period (Altenbach et al 2003; Hurkman et al 2003). An elevated temperature during growth has also been reported to alter A- to B-type granule ratios (Shi et al 1994; Tester et al 1995; Panozzo and Eagles 1998; Hurkman et al 2003), slightly increase amylose and bound lipid levels (Shi et al 1994; Blumenthal 1995; Tester et al 1995; Panozzo and Eagles 1998), and subtly alter the amylopectin fine structure (Shi et al 1994) of wheat starch.

A majority of studies utilized experimentally controlled or highly regulated growing environments to successfully elucidate effects of specific environmental parameters on starch characteristics, while minimizing confounding effects. Through such efforts, it has been possible to understand how a particular environmental condition would be expected to affect starch characteristics and to identify the starch characteristics most likely to vary under a specific growing condition. However, there is further need to extend these findings to more complex and traditional cropping systems (field level), in which environmental conditions are not controlled and where multiple environmental factors may exert simultaneous influence. It will be important to identify the predominant starch characteristics within a flour that best account for observed environment-induced differences in flour/starch properties. Identification of these governing characteristics will help direct research focus toward the most significant starch biosynthetic pathways that need to be understood to manipulate and improve wheat quality.

The approach of this study involved investigation of flour/starch characteristics (flour total starch content, granule type/size, and total/apparent/lipid-complexed amylose levels) of wheat (wild-type, partial waxy) cultivated at two diverse growing locations over two successive crop years. Growing locations (Tetonia, ID/rain-fed and Aberdeen, ID/irrigated) represented diverse growing environments, and were purposely selected to provide a range of flour/starch characteristics for study. The objective of this study was not to relate observed fluctuations in flour/starch characteristics to specific climatic conditions, environmental factors, or management schemes, but instead to identify variable flour/starch characteristics within wheat flour that could potentially explain observed environment-induced fluctuations in flour pasting properties.

MATERIALS AND METHODS

Wheat Source, Milling, and Starch Isolation

Soft spring wheat genotypes used in the study varied according to granule bound starch synthase I (GBSSI) class and consisted of wild-type (Jubilee and Whitebird), one gene null partial waxy (Alturas and Penawawa: *Wx-B1a*), and two gene null partial waxy (IDO563 and IDO565: *Wx-A1a, Wx-B1a*). All genotypes were derived from common parentage (excepting Penawawa) with coefficients of parentage similar to half sibs or closer, and were grown at two diverse Idaho locations (Aberdeen/irrigated and Tetonia/rain-fed) over two successive crop years (2000, 2001) to enhance the likelihood for environmental variability. A total of 24 (6 genotypes × 2 crop years × 2 growing locations) genotype/crop year/growing location combinations were utilized in the study. For each genotype/crop year/growing location combination, grain was milled to straight-grade flour and native starch (defined as the population of starch granules present in straight-grade flour) was isolated from milled flours as described in a companion article (Geera et al 2005a).

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Measurement of Starch Granule Size Distribution

Granule size distributions of native starches (representing each genotype/crop year/growing location combination) were determined using an Accusizer model 780 with SW 788 Windows software (Particle Sizing Systems, Santa Barbara, CA) as described previously (Geera et al 2005a). A 10-μm cutoff was used to differentiate A- and B-type starch granule populations.

Determination of Amylose

Apparent (AAM), total (TAM), and lipid-complexed (LAM) amylose contents of native starch granule fractions were determined using the colorimetric method of Morrison and Laignelet (1983). The AAM content was measured before the removal of starch lipids, while TAM was determined on defatted starch. The difference between TAM and AAM provided a measure of LAM.

Evaluation of Flour/Starch Pasting Properties

Pasting properties of straight-grade flours representing each genotype/crop year/growing location were determined as outlined by Batey et al (1997) using a Rapid Visco Analyser (RVA) (Newport Scientific, NSW, Australia). Flour (3.5 g, db) was weighed into an RVA canister followed by addition of silver nitrate solution (0.012*M*) to achieve a final net weight of 29.0 g. Flour suspensions were analyzed under continuous shear (160 rpm) beginning with an initial hold at 60°C (2 min), linear heating to 95°C (5 min), an intermediate hold at 95°C (4 min), linear cooling to 50°C (5 min), and a final hold at 50°C (4 min) to yield a total test time of 20 min.

Miscellaneous Analyses

Moisture contents of straight-grade flours and the respective native starches were determined according to AOAC Method 925.09 (AOAC 1990). Flour total starch contents were determined using the Megazyme Total Starch Assay (Approved Method 76-13; AACC International 2000). Isolated native starch yields from straight-grade flour were reported as grams of starch (db) recovered from 100 g of flour (db).

Experimental Design

Flour total starch assays, native starch isolation from flour, and RVA flour pasting experiments were replicated twice for straight-grade flours of each genotype/crop year/growing location combination. Particle size analysis and amylose characteristic determinations were conducted for each replicate isolation of native starch.

To test for the effect of growing environment using ANOVA, experimental main effects (crop year and growing location) were analyzed across genotypes for all flour/starch characteristics and properties. All possible interactions were also evaluated. Differences among mean flour/starch characteristic and flour pasting

TABLE I
Mean Flour Pasting Attributes by Growing Environment[a,b]

Crop Year/Location	Peak Viscosity	Breakdown Viscosity	Trough Viscosity	Final Viscosity	Setback Viscosity
2000/Aberdeen	399.6 ± 32.9	246.3 ± 43.2	153.2 ± 17.2	309.2 ± 44.8	156.0 ± 28.0
2001/Aberdeen	411.0 ± 24.4	255.5 ± 31.2	155.4 ± 18.0	316.2 ± 48.8	160.7 ± 31.3
2000/Tetonia	402.5 ± 28.0	238.9 ± 43.1	163.5 ± 19.9	330.8 ± 47.4	167.2 ± 27.8
2001/Tetonia	359.4 ± 27.1	202.2 ± 38.4	157.1 ± 18.8	313.2 ± 48.0	156.1 ± 29.2
Overall mean	393.1	237.7	629.2	317.4	160.0
Spread	51.6	53.3	10.3	21.6	11.2

[a] Mean values represent pooled genotype attributes for each growing environment.
[b] Pasting attribute values are depicted in Rapid Visco Analyser units (RVU).

TABLE II
Mean Flour/Starch Characteristics by Growing Environment[a,b]

Crop Year/Location	FTS	NSY	A-Type	TAM	AAM	LAM
2000/Aberdeen	86.1 ± 1.1	83.6 ± 0.5	72.6 ± 2.4	22.3 ± 0.2	17.4 ± 0.2	4.9 ± 0.0
2001/Aberdeen	86.6 ± 1.4	83.9 ± 1.1	74.5 ± 2.2	21.7 ± 0.0	17.1 ± 0.1	4.5 ± 0.1
2000/Tetonia	86.4 ± 2.3	83.9 ± 0.8	77.3 ± 1.6	21.9 ± 1.0	16.8 ± 1.2	5.1 ± 0.2
2001/Tetonia	83.9 ± 2.4	81.1 ± 1.6	72.5 ± 2.1	22.4 ± 0.1	16.9 ± 0.1	5.5 ± 0.2
Overall mean	85.8	83.1	74.2	22.1	17.1	5.1
Spread	2.7	2.8	4.8	0.6	0.6	1.0

[a] Mean values represent pooled genotype characteristics for each growing environment.
[b] FTS, flour total starch (g/100 g of flour); NSY, native starch yield (isolated starch yield from flour) (g/100 g of flour); A-type granules by weight (g/100 g of native starch); TAM, total amylose (g/100 g of native starch); AAM, apparent amylose (g/100 g of native starch); LAM, lipid-complexed amylose (g/100 g of native starch).

TABLE III
Analysis of Variance Level of Significance for Effects of Genotype, Crop Year, Growing Location, and Interactions on Flour/Starch Characteristics[a,b]

Source	df	Peak	Trough	Breakdown	Final	Setback	FTS	NSY	A-Type	TAM	AAM	LAM
Genotype (G)	5	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Year (Y)	1	<0.0001	0.0171	<0.0001	0.0002	<0.0001	0.0004	<0.0001	<0.0001	0.7886	0.6622	0.9568
Location (L)	1	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.3496	0.0083	0.0008
G × L	5	<0.0001	0.0100	<0.0001	0.0001	<0.0001	<0.0001	0.1468	<0.0001	0.0032	<0.0001	0.0422
G × Y	5	<0.0001	0.1801	<0.0001	0.0020	<0.0001	0.0394	0.0002	0.0024	0.2878	0.3294	0.0438
L × Y	1	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0091	0.2025	0.0198
G × Y × L	5	0.0002	0.2579	<0.0001	0.1767	0.4631	<0.0001	0.0099	0.0002	0.0731	0.0039	0.5639

[a] Statistical significance level set at $P < 0.05$.
[b] Peak, flour peak viscosity; Trough, flour trough viscosity; Breakdown, flour breakdown viscosity; Setback, flour setback viscosity; Final, flour final viscosity; FTS, flour total starch (g/100 g of flour); NSY, native starch yield (isolated starch yield from flour) (g/100 g of flour); A-type granules by weight (g/100 g of native starch); TAM, total amylose (g/100 g of native starch); AAM, apparent amylose (g/100 g of native starch); LAM, lipid-complexed amylose (g/100 g of native starch).

attribute mean values (pooled across genotypes) were determined using LSD tests ($P < 0.05$). Correlation analysis was conducted across all crop year/growing location combinations calculated across genotypes and also by genotype to assess the basis for environment-induced fluctuations in flour pasting properties. All statistical analyses were computed using SAS v. 8.2 for Windows (SAS Institute, Cary, NC).

RESULTS AND DISCUSSION

Environment-Induced Variation of Flour/Starch Characteristics and Properties

The purpose of this study was to consider the effect of growing environment on flour/starch characteristics with emphasis on identification of varying flour/starch characteristics that could potentially explain observed environment-induced fluctuations in flour pasting properties. No attempt was made to relate flour/starch characteristics or property fluctuations to specific environmental conditions as this aspect was beyond the scope of study. The extent of variation for flour pasting properties and flour/starch characteristics observed across growing environments (four crop year/growing location combinations) was studied.

Mean values for flour/starch characteristics (calculated across all genotypes) for each of the four growing environments as well as the extent of variation observed for each flour/starch attribute across growing environments are depicted in Tables I and II. Though all flour pasting attributes varied considerably, peak and breakdown viscosities exhibited more variability across growing environments relative to trough, setback, and final viscosities (Table I). In Table II, mean flour total starch (FTS) contents for the four growing environments paralleled observed fluctuations in isolated native starch yields (NSY) from flour, as would be expected. Mean A-type granule contents of isolated native starches (indicative of A/B-type granule ratios within parent flours) also varied appreciably in response to growing environment but did not follow the pattern observed for FTS and NSY from flour. Total (TAM), apparent (AAM), lipid-complexed (LAM) amylose mean values exhibited minimal variability across growing environments as previously reported for wheat (Tester and Karkalas 2001). While growing environment exerted only subtle effects on amylose characteristics, both FTS and A-type granule contents showed greater degrees of variation across growing environments and appeared to offer potential for explanation of flour pasting property fluctuations.

Crop Year and Growing Location Main Effects

Based on analysis of variance (ANOVA), significant differences were observed among genotypes, growing locations, and crop years with respect to flour/starch characteristics and properties (Table III). Significant two- and three-way interactions between genotype and other main effects (crop year, growing location) were observed for all flour/starch characteristics and pasting attributes. However, all such interactions were deemed nonsevere (no crossover effects) and of no practical significance after analysis of interaction plots as all genotypes responded similarly across growing environments (data not shown). As previously noted, genotype differences including analysis of waxy lines were the focus of a companion article (Geera et al 2005a) and will not be further addressed here. All measured flour/starch characteristics and flour pasting properties, with the exception of amylose characteristics (TAM, AAM, and LAM), were universally affected by both crop year and growing location main effects (Table III). No amylose characteristics were significantly influenced by crop year, while only AAM and LAM exhibited statistical significance for the growing location main effect. Significant interactions between crop year and growing location were evident for most flour pasting attributes and flour/starch characteristics (Table III). These particular interactions were deemed to be severe (of practical significance).

In pooling genotype data across growing locations, significant differences between crop years were observed for all flour pasting attributes as well as FTS, NSY, and A-type granule contents (Table IV). Crop year did not significantly affect amylose characteristics. Crop year 2000, which exhibited the highest mean values for all pasting attributes (peak, breakdown, setback, and final viscosities) also exhibited the highest mean FTS and A-type granule contents relative to crop year 2001. Both high FTS and A-type granule contents have been associated with elevated pasting viscosity values (Shinde et al 2003; Geera et al 2005b). Thus, crop year fluctuations in flour pasting properties could be potentially explained, in part, by variations in FTS and A/B-type granule contents.

In pooling genotype data across crop years, significant differences were noted between Aberdeen and Tetonia growing locations

TABLE IV
Mean Flour Pasting Attributes and Flour/Starch Characteristics by Crop Year[a–c]

Crop Year	Peak	Breakdown	Trough	Final	Setback	FTS	NSY	A-Type	TAM	AAM	LAM
2000	401.1a	242.6a	158.4a	320.0a	161.6a	86.3a	83.7a	74.9a	22.1a	17.1a	5.0a
2001	385.2b	228.9b	156.0b	314.7b	158.4b	85.3b	82.5b	73.4b	22.0a	17.0a	5.0a

[a] Mean values represent pooled genotype characteristics by crop year; values within a column followed by the same letter are not significantly different (P <0.05).

[b] Pasting attribute values are reported in Rapid Visco Analyser units (RVU).

[c] Peak, flour peak viscosity; Trough, flour trough viscosity; Breakdown, flour breakdown viscosity; Setback, flour setback viscosity; Final, flour final viscosity; FTS, flour total starch (g/100 g of flour); NSY, native starch yield (isolated starch yield from flour) (g/100 g of flour); A-type granules by weight (g/100 g of native starch); TAM, total amylose (g/100 g of native starch); AAM, apparent amylose (g/100 g of native starch); LAM, lipid-complexed amylose (g/100 g of native starch).

TABLE V
Mean Flour Pasting Attributes and Flour/Starch Characteristics by Growing Location[a–c]

Location	Peak	Breakdown	Trough	Final	Setback	FTS	NSY	A-Type	TAM	AAM	LAM
Aberdeen	405.3a	250.9a	154.3b	312.7b	158.4b	86.4a	83.8a	73.5b	22.0a	17.3a	4.7b
Tetonia	381.0b	220.6b	160.4a	322.0a	161.7a	85.2b	82.5b	74.9a	22.2a	16.9b	5.3a

[a] Mean values represent pooled genotype characteristics by crop year; values within a column followed by the same letter are not significantly different, $p<0.05$.

[b] Pasting attribute values are depicted in Rapid Visco Analyzer units (RVU).

[c] Peak, flour peak viscosity; Trough, flour trough viscosity; Breakdown, flour breakdown viscosity; Setback, flour setback viscosity; Final, flour final viscosity; FTS, flour total starch (g/100 g of flour); NSY, native starch yield (isolated starch yield from flour) (g/100 g of flour); A-type granules by weight (g/100 g of native starch); TAM, total amylose (g/100 g of native starch); AAM, apparent amylose (g/100 g of native starch); LAM, lipid-complexed amylose (g/100 g of native starch).

in regard to FTS levels, A/B-type granule contents, amylose characteristics (AAM, LAM), and flour pasting attributes (Table V). Aberdeen mean flour peak and breakdown viscosities were higher compared with those obtained from Tetonia, while Tetonia mean trough, setback, and final viscosities were higher relative to those of Aberdeen. The highest mean pasting attributes were not universally observed at a single location but were split between Aberdeen (peak and breakdown viscosities) and Tetonia (trough, setback, and final viscosities) growing locations. Likewise, the highest FTS and A-type granule content mean values were also split between the two growing locations, mirroring the pattern observed for flour pasting attributes. The highest mean peak and breakdown viscosities were observed for Aberdeen, which also possessed the highest mean FTS content. Conversely, the highest mean trough, setback, and final viscosities were observed for Tetonia, which exhibited the highest mean A-type granule content. Amylose characteristic (AAM, LAM) differences between the two locations appeared to be predominantly a function of LAM levels (no significant difference noted in TAM content), which are more likely to vary in response to growing environment than actual amylose values (Tester and Karkalas 2001). Fluctuations in starch granule bound lipids, though very small, could also have contributed somewhat to mean pasting attribute differences noted between Aberdeen and Tetonia.

As previously mentioned, there were significant interactions between crop year and growing location main effects (Table III), as the two growing locations did not always respond similarly across crop years with respect to individual flour/starch characteristics. Plots of these relationships further revealed that the nature of the interaction patterns differed according to the flour/starch characteristic analyzed and that various flour/starch characteristics exhibited common patterns (Figs. 1 and 2). Both FTS content and NSY from flour varied in similar fashion to peak and breakdown viscosities, while A-type granule content exhibited a similar pattern to trough, setback, and final viscosities. These findings provide further evidence that variations in flour/starch characteristics were potentially associated with corresponding changes in flour pasting properties.

Explanation of Environmental Effects

To further investigate the basis for observed environment-induced fluctuations, correlation analysis was conducted to assess associations between flour/starch characteristics and flour pasting behaviors across the four growing environments using overall growing environment mean values (calculated across all genotypes). Correlation coefficients among RVA attributes themselves fell into two primary groupings. Significant associations were noted between peak and breakdown viscosities while trough, final, and setback viscosities were intercorrelated (Table VI). Fluctuations in FTS, A-type granule content, and amylose characteristics accounted for much of the environmental variation associated with flour RVA pasting attributes.

Flour peak viscosity was most highly correlated (positively) with FTS and NSY from flour (Table VI), suggesting that fluc-

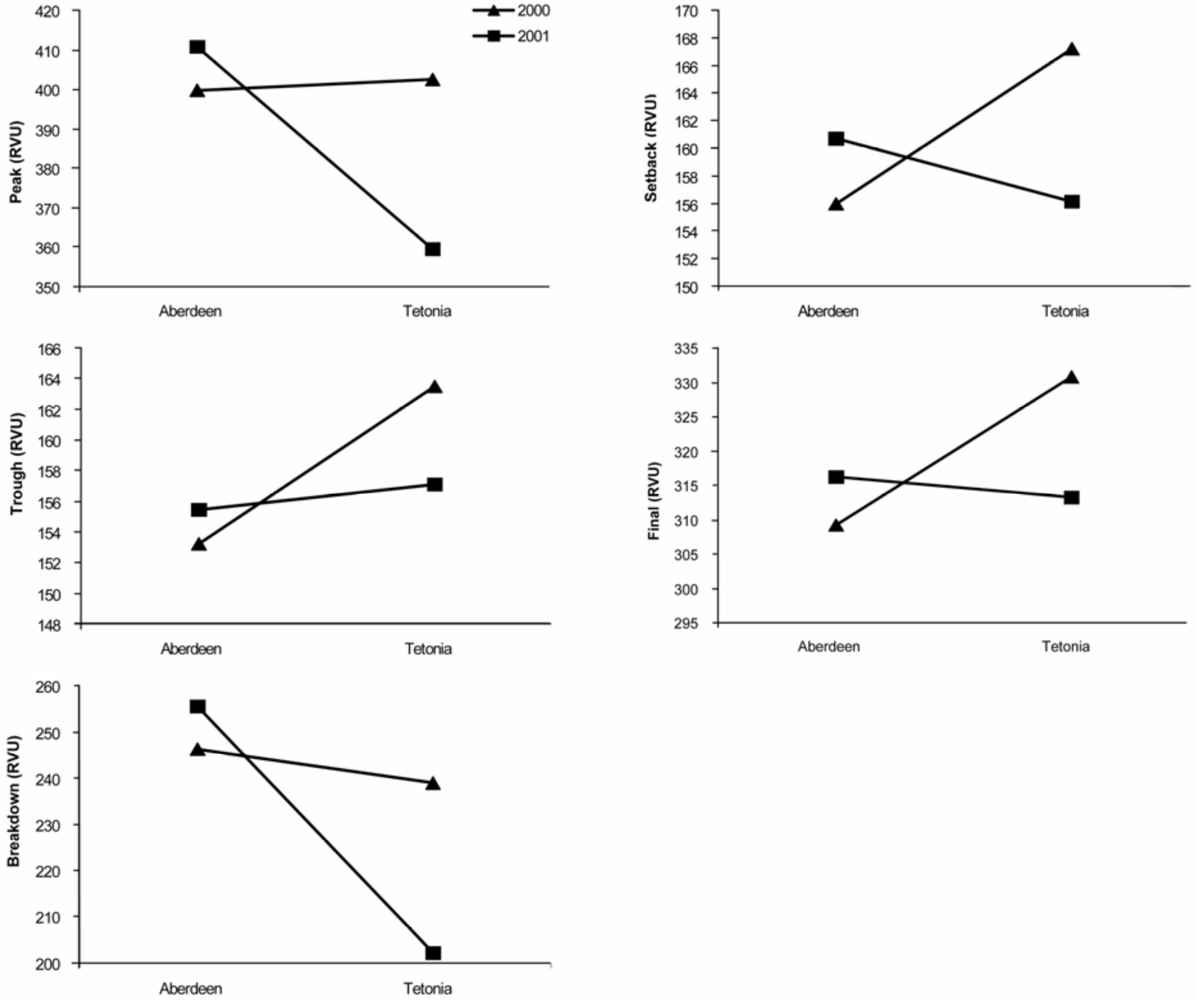

Fig. 1. Crop year × growing location interaction plots for flour pasting properties.

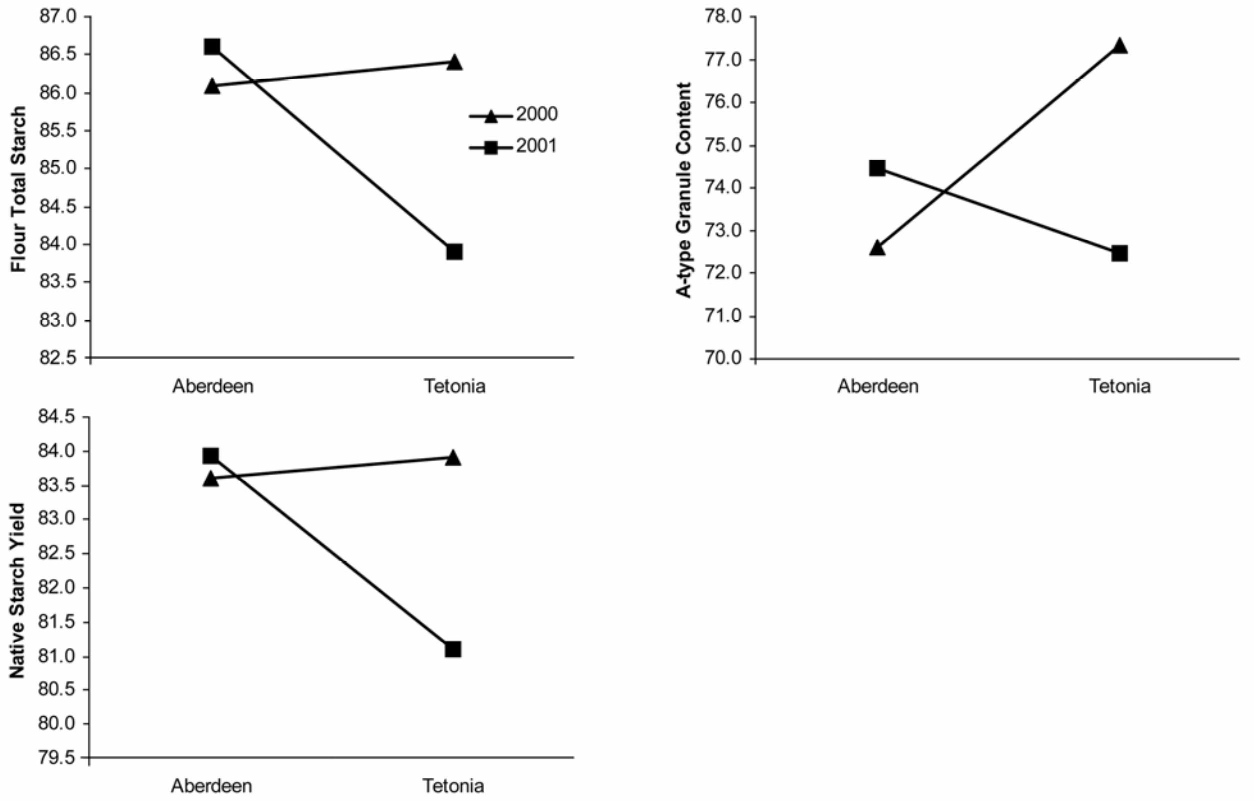

Fig. 2. Crop year × growing location interaction plots for flour/starch characteristics.

TABLE VI
Correlation Coefficients (*r*) Among Flour/Starch Characteristics and Flour Pasting Attributes[a,b]

	Trough	Breakdown	Setback	Final	TFS	NSY	A-Type	TAM	AAM	LAM
Peak	0.03	0.98*	0.51	0.30	0.95*	0.99*	0.52	–0.78*	0.20	–0.72*
Trough		–0.17	0.83*	0.95*	0.05	0.10	0.82*	–0.30	–0.69	0.29
Breakdown			0.34	0.11	0.93*	0.95*	0.36	–0.71	0.34	–0.76*
Setback				0.96*	0.54	0.56	0.99*	–0.65	–0.39	–0.19
Final					0.33	0.36	0.96*	–0.51	–0.56	0.03
TFS						0.93*	0.55	–0.67	0.16	–0.61
NSY							0.58	–0.72*	0.20	–0.68
A-Type								–0.64	–0.42	–0.16
TAM									0.07	0.68
AAM										–0.68

[a] Significant at $P < 0.05$; $n = 8$.

[b] Peak, flour peak viscosity; Trough, flour trough viscosity; Breakdown, flour breakdown viscosity; Setback, flour setback viscosity; Final, flour final viscosity; FTS, flour total starch (g/100 g of flour); NSY, native starch yield (isolated starch yield from flour) (g/100 g of flour); A-type granules by weight (g/100 g of native starch); TAM, total amylose (g/100 g of native starch); AAM, apparent amylose (g/100 g of native starch); LAM, lipid-complexed amylose (g/100 g of native starch).

tuations in peak viscosity were explained by corresponding changes in FTS content. In addition, TAM and LAM exhibited significant negative correlations of relatively lesser strength with flour peak viscosity compared with those between FTS and peak viscosity. Increases in amylose content have been generally associated with decreased peak viscosities (Zeng et al 1997). Breakdown viscosity also exhibited positive associations with FTS and NSY and an inverse correlation with LAM. No significant correlation was observed between A-type granule content and either peak or breakdown viscosities. In contrast, Shinde et al (2003) reported significant correlation between A-type granule content and both pasting attributes while investigating contributions of A- and B-type granules to wheat starch pasting behavior. Possible associations between these parameters in our study were likely overshadowed by significant fluctuations in FTS content, which was the dominant factor associated with peak and breakdown viscosity variation. In summary, environmental fluctuation of peak and breakdown viscosities was primarily explained by variation in FTS content, and likely secondarily affected by subtle differences in amylose characteristics (TAM, LAM).

In contrast, trough, final, and setback viscosities were positively correlated with A-type granule content (Table VI) in agreement with previous reports that A-type granules consistently displayed higher trough, final, and setback viscosities relative to B-type granules (Shinde et al 2003; Geera et al 2005b). Neither FTS or NSY exhibited significant correlation with any of these three pasting attributes. Thus environment-based fluctuations in A-type granule content appeared to offer the best explanation for variation of flour trough, final, and setback viscosities for the flour/starch characteristics measured.

Further statistical analysis was conducted to determine the extent to which relationships obtained for the overall correlation analysis, based on growing environment mean values across genotypes, could be observed within the individual genotypes.

TABLE VII

Correlation Coefficients (*r*) Among Select Pairs of Flour/Starch Characteristics and Flour Pasting Attributes for Individual Genotypes[a,b]

Charactertistic Pair	Jubilee	Whitebird	Alturas	Penawawa	IDO563	IDO565
NSY–Peak	0.80*	0.92*	0.89*	0.96*	0.98*	0.96*
NSY–Breakdown	0.85*	0.88*	0.71*	0.92*	0.97*	0.97*
A-type–Trough	0.55	0.60	0.89*	0.86*	0.38	0.74*
A-type–Setback	0.95*	0.77*	0.89*	0.78*	0.87*	0.90*
A-type–Final	0.82*	0.91*	0.90*	0.84*	0.69	0.88*

[a] Significant at $P < 0.05$; $n = 8$.

[b] NSY, native starch yield (isolated starch yield from flour, g/100 g of flour); A-type granules by weight (g/100 g of native starch).

Table VII provides correlation coefficients between select pairs of starch characteristics and RVA flour pasting attributes according to genotype. For all six genotypes, NSY exhibited consistent positive correlations with both flour peak and breakdown viscosities. Similarly, A-type granule content was positively correlated with flour trough, final, and setback viscosities for three, five, and all six of the genotypes of the study, respectively. Thus there was good agreement between the overall correlation analysis and those conducted for the individual genotypes, providing additional support for the observation that all genotypes of the study generally responded in similar manner to the growing environment effects measured.

SUMMARY AND CONCLUSIONS

Variation in flour/starch characteristics appeared to explain, in part, environment-induced fluctuations in the flour pasting behaviors. Flour total starch and A/B-type granule contents were significantly influenced by both crop year and growing location main effects in contrast to amylose characteristics (TAM, AAM, and LAM) that were only minimally affected by the growing environment. The crop year or growing location that exhibited the highest mean FTS contents also exhibited the highest mean peak and breakdown viscosities. Similarly, the growing location or crop year that possessed the highest mean A-type granule content also displayed the highest mean trough, final, and setback viscosities. Interaction plots between crop year and growing location showed that peak and breakdown viscosities responded similarly to FTS contents, while trough, final, setback, and final viscosities behaved in similar fashion to A- and B-type granule contents. Correlation analysis provided additional evidence for relationships between flour/starch characteristics and flour pasting behaviors. In summary, fluctuations in flour peak and breakdown viscosities appeared to be best explained by fluctuations in FTS contents, while fluctuations in all other pasting attributes (trough, setback, and final viscosities) were explained in part by variability in A- and B-type granule contents. The difficulty in understanding the basis for environment-based fluctuations lies in the fact that multiple flour/starch characteristics vary simultaneously with potentially differing or confounding effects on properties, as was the case here. In this particular study, fluctuations in FTS and A/B-type granule contents best explained flour pasting property fluctuations associated with growing environment, though each of the two characteristics (FTS and A/B-type granule content) primarily affected different pasting attributes. These findings shed additional light on the complexity of growing environment-induced effects. Both FTS and A/B-type granule would appear to be important factors to consider in investigating environmental effects associated with wheat flour/starch pasting behavior.

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